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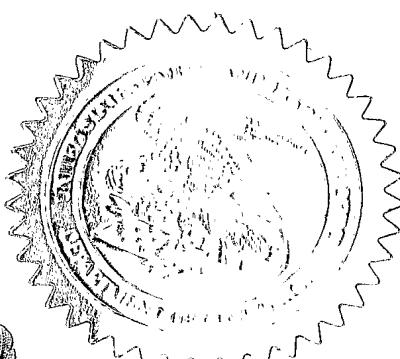
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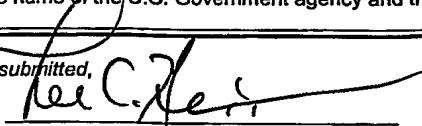
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TITLE OF THE INVENTION (500 characters max)		
ACTIVE MATERIALS FOR TIME TEMPERATURE INDICATORS		
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[Page 1 of 2]

Respectfully submitted,

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Date April 22, 2004REGISTRATION NO. 41,827

(if appropriate)

Docket Number: 26113

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Docket Number 26113

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[Page 2 of 2]

Number 2 of 2

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MAIL STOP PROVISIONAL PATENT APPLICATION
Attorney Docket No. 26113

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:

LEVY et al.

Serial No. NOT YET ASSIGNED

Filed: April 22, 2004

For: ACTIVE MATERIALS FOR TIME TEMPERATURE INDICATORS

TRANSMITTAL LETTER

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

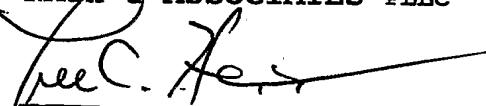
Submitted herewith for filing in the U.S. Patent and Trademark Office is the following **PROVISIONAL APPLICATION**:

- (1) Transmittal Letter
- (2) Cover sheet for filing Provisional Application
- (3) 39 page Provisional Application consisting of:
 - 25 pages Textual Specification with imbedded drawings,
 - 8 pages of 33 Claims,
 - 0 page of the Abstract,
 - 6 sheets of Drawings;
- (4) Check No. 20854 \$ 80.00 for filing fee as a small entity;
- (5) Postcard for early notification of serial number.

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Respectfully submitted,
NATH & ASSOCIATES PLLC

By:



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ACTIVE MATERIALS FOR TIME TEMPERATURE INDICATORS

FIELD OF THE INVENTION

This invention is generally in the field of time temperature indicators, and relates to active materials used therein.

BACKGROUND OF THE INVENTION

5 Time temperature indicators, TTIs, are substrates for packaging of or attachment to perishable goods that are capable of reporting the partial or full time temperature history of any good to which it is thermally coupled.

Temperature abuse is one of the most frequently observed causes for predicated goods spoilage. It is therefore important and desired to monitor the
10 time-temperature history of such perishable goods, preferably, using inexpensive and consumer friendly means.

Time temperature indicators are substances that are capable of visually reporting on the summary of the time temperature history of the substance, and consequently, of the perishable good it is associated with. Designed for the end
15 user, time temperature indicators are usually designed to report a clear and visual Yes/No signal.

WO 99/39197 describes the use of photochromic dyes, based on a transfer reaction and embedded in the crystalline state, as active materials for TTIs. TTIs based on these materials are highly accurate and reproducible and can be charged
20 using stimulating light.

Some basic limitations of most photochromic materials arise from the fact that the colored photoproduct is sufficiently photoactive to introduce undesired light effects to the time temperature profile. For example, the photosensitivity of the uncharged and charged species of a time temperature monitor based on 2-5 (2,4-dinitrobenzyl)-3-methylpyridine is provided in **Figs. 1a and 1b**. As can be seen, the photobleaching of the colored species is achieved even by modest ambient light. According to WO 99/39197, this problem can be overcome by placing a special filter atop the active substance, thus filtering most of the UV and visible spectrum.

10 SUMMARY OF THE INVENTION

The present invention provides a novel time temperature indicator using compound(s) of diarylethenes, preferably Formula I (see below), and/or spiroaromatics compound(s), preferably of Formula II (see below), as active material of the TTI. Preferably, the active material is in a crystallite form.

15 In a specific embodiment of the invention, the compounds of Formula I are symmetric diarylethenes such as 1,2-dicyano-1,2-bis(2,4,5-trimethylthiophene-3-yl)ethane; 2,3-bis(2,4,5-trimethylthiophene-3-yl)maleic anhydride; 1,2-bis(2-cyano-1,5-dimethyl-4-pyrrolyl)perfluorocyclopentene; and 1,2-bis(2,4-dimethyl-5-phenylthiophene-3-yl)perfluorocyclopentene.

20 In another specific embodiment, the compounds of Formula I are asymmetric diarylethenes such as 2-(1,2-dimethyl-3-indolyl)-3-(2,4,5-trimethyl-3-thienyl) maleic anhydride; 2-(methoxybenzo[b]thiophene-3-yl)-3-(1,2-dimethyl-3-indolyl) maleic anhydride.

In yet another embodiment of the present invention, the compounds of 25 Formula II are spiropyrans derivatives such as 1',3',3'-trimethyl-6-nitro-spiro(2H-1-benzopyran-2,2'-2H-indole); 1',3',3'-trimethyl-6,8-dinitro-spiro(2H-1-benzopyran-2,2'-2H-indole); 6-(4-nitrophenylazo)-1',3',3'-trimethyl-spiro(2H-1-benzopyran-2,2'-2H-indole); and 6-(4-chlorophenylazo)-1',3',3'-trimethyl-spiro(2H-1-benzopyran-2,2'-2H-indole).

In yet another embodiment, the compounds of Formula II are charged.

In yet another specific embodiment, the compounds of Formula II are spirooxazines, spironaphthoxazines, or spiroindolinopyridobenzoxazines.

In accordance with another aspect of the present invention, there is 5 provided a means of producing a time temperature indicator having active matrices that contain diarylethene and/or spiroaromatic materials.

In yet another aspect of the present invention, there is provided a method for the manufacture of a TTI comprising an active material including at least one compound selected from diarylethenes and spiroaromatics, said method 10 comprising: embedding in or a top a suitable matrix said at least one compound; and inducing formation of a metastable state of the embedded said at least one compound. In one embodiment, the method further comprises covering said TTI with a suitable cover support. In one specific case, the cover support is designed to avoid photo recharging or photo bleaching.

15

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

20 **Figs. 1A and 1B** schematically illustrate the photosensitivity of the uncharged and charged species of a time temperature monitor based on 2-(2,4-dinitrobenzyl)-3-methylpyridine (Prior Art).

Fig. 2 depicts the synthesis of compound **11**.

Fig. 3 depicts the reversion of the metastable **11** to colorless **11**.

25 **Fig. 4** depicts reversion of metastable **11** as a function of temperature.

Fig. 5 graphically illustrates the fading rate of **11** in terms of its activating energy and preexponential factors.

Fig. 6 depicts the synthesis of compounds **12** and **14**.

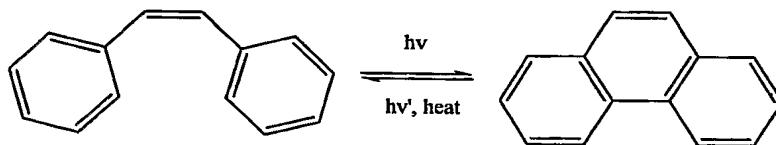
Fig. 7 depicts the synthesis of compounds **13** and **15**.

DETAILED DESCRIPTION OF THE INVENTION

Diarylethenes and spiroaromatic compounds, as known in the art, are reversible and bistable photochromic materials that exhibit a change in color in response to time and/or temperature changes, as well as light changes.

5 Normally, in diarylethenes, the open form is transparent, while the cyclic form is colored. The open form is normally the thermodynamically stable species, while the closed form is either a stable state or a metastable one. One specific example of the reversible process of ring-closure/ring-opening of diarylethene, namely, of styrene is shown below.

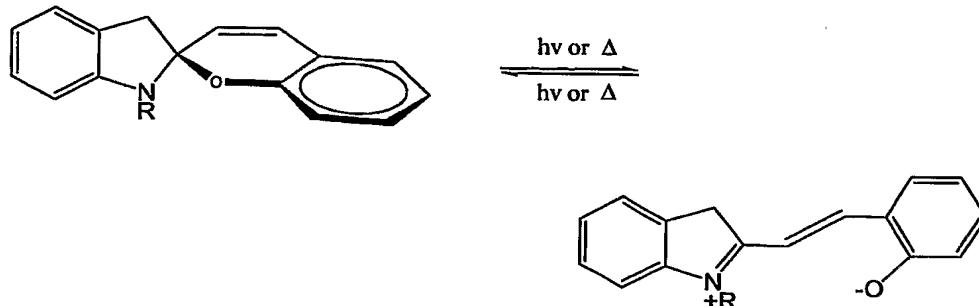
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The most striking feature of these compounds is their resistance to fatigue. The coloration-discoloration cycle could be repeated more than 10^4 times
15 maintaining the photochromic performance.

In spiroaromatic derivatives, the closed form is normally the thermodynamically preferred state:

20



In cases where the activation energy is appropriate, the ring opening of the closed form of diarylethenes and the ring closure of spiroaromatic materials can

be utilized in the monitoring of the time temperature history of the material, relaying on the color change associated with these processes.

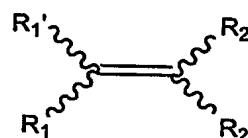
Of all diarylethene and spiroaromatic derivatives, materials that exhibit the following characteristics are especially suitable for TTI applications:

- 5 1) The system has at least one thermal process leading from one metastable state to one stable state, where the two states are characterized by a distinctly different color and/or any other measurable physical parameter such as luminescence, refraction index, conductivity and the like;
- 10 2) The stable state may be converted to the metastable state using one or any combination of stimuli, among others the following processes:
 - a) photonic induction, b) thermal induction, c) pressure induction, d) electrical induction, or e) chemical induction; and
 - 15 3) Other than temperature, the metastable state is substantially not affected by anyone or any combination of stimuli such as a) photo induction, b) piezo induction, c) electro induction, d) chemo induction.

The active material of the present invention may be in the form of a crystal or a polycrystalline powder, in which the forward and reverse reactions take place or alternatively may be in a form of any other solid phase such as a glass, a polymer solution or attached to a polymer, or in the form of a liquid or a 20 solution.

Diarylethenes

In accordance with a first aspect of the present invention, the active material suitable for use in time temperature indicators may be one or more 25 compounds having the diarylethene backbone, which fulfill the requirements disclosed hereinabove and have general Formula I:



Formula I

wherein

- R1 and R2 each independently represents C6-C14 aryl, C4-C12 heteroaryl, conjugated heterocyclic; wherein said heteroaryl and conjugated heterocyclic may contain one to three heteroatoms selected from N, O, or S; and
- 5 wherein said aryl, heteroaryl, or conjugated heterocyclic may be substituted by one or more halogen, hydroxyl, thiol, amino, C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, cyano, nitro, sulfo, -CH=CH-CN, azido, or
- 10 amido;
- R1' and R2' each independently represents H, cyano, nitro, sulfo, hydroxyl, thiol, -CH=CH-CN, or amido; or substituted or unsubstituted C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic
- 15 carbocyclic, C3-C8 membered ring non-aromatic heterocyclic; or R1' and R2' together with the carbon atoms to which they are attached form a C5-C8 carbocyclic ring or a C4-C7 heterocyclic ring containing one to three endocyclic or exocyclic heteroatoms selected from N, O, or S; said N heteroatom may be further substituted by H, or by one or two substituted or unsubstituted groups
- 20 selected from C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, hydroxyl, or -CH=CH-CN; when said N heteroatom is tetrasubstituted it is positively charged and is associated with an anion selected
- 25 from the group consisting of organic or inorganic anions;
- R1, R1', R2 and R2' may each represent a charged group or a group substituted by another group having a charge; said charge may be localized or delocalized and may be positive or negative, resulting from charged groups such as ammonium, phosphonium, phenolate, carboxylate, sulphonate, thiolate,
- 30 selenate and the like;

and wherein said R1 and R2 may be in a *cis* or *trans* conformation.

In one embodiment, the compounds of Formula I are zwitterions in which one of the groups R1, R1', R2, or R2' may be positively charged and one other groups may be negatively charged.

- 5 In one specific embodiment, the compounds of Formula I are those wherein R1 and R2 are each independently a substituted heteroaryl containing one to three heteroatoms selected from N, O, or S; wherein said heteroaryl is substituted by one or more halogen, C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, cyano, nitro, sulfo, -CH=CH-CN, azido, amido or amino; R1' and R2' each independently represents H, C1-C12 alkyl, C2-C12 alkenyl, cyano, nitro, or -CH=CH-CN, or R1' and R2' together with the carbon atoms to which they are attached form a C5-C8 carbocyclic ring or a C4-C7 heterocyclic ring containing one to three endocyclic or exocyclic heteroatoms selected from N, or O; said N heteroatom is further substituted by H, or by a substituted or unsubstituted C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, or -CH=CH-CN; and wherein said C5-C8 carbocycle is substituted by one or more halogen, preferably by one or more fluoro atoms.
- 10 In another specific embodiment, R1 and R2 are identical and are selected from substituted or unsubstituted indoles, pyrroles, thiophenes, benzthiophenes or furans. In this embodiment R1' and R2' are also identical and are selected from cyano, C1-C6 alkyl, or C6-C14 aryl.
- 15 In yet another embodiment, R1 and R2 are selected from substituted or unsubstituted thiophenes, benzthiophenes, indoles or pyrroles; and R1' and R2' together with the carbon atoms to which they are attached form a cyclopentyl, cyclohexyl, or an anhydride ring; said cyclopentyl or cyclohexyl being further substituted by one or more halogen, C1-C6 alkyl, C6-C14 aryl, hydroxyl, amino, nitro, or cyano groups. Preferably, the cyclopentyl or cyclohexyl are substituted by halogens. Most preferably they are perfluorinated.
- 20
- 25
- 30

Examples of symmetric diarylethenes which are suitable for use with the TTIs of the present invention, and which are encompassed in the general Formula I are (structures shown in Appendix A):

- 5 (1) 1,2-dicyano-1,2-bis(2,4,5-trimethylthiophene-3-yl)ethane
(2) 2,3-bis(2,4,5-trimethylthiophene-3-yl)maleic anhydride
(3) 1,2-bis(2-cyano-1,5-dimethyl-4-pyrrolyl)perfluorocyclopentene
(4) 1,2-bis(2,4-dimethyl-5-phenylthiophene-3-yl)perfluorocyclopentene

10 Examples of asymmetric diarylethenes which are suitable for TTIs and which are encompassed with in general Formula I are (structures shown in
10 Appendix A):

- 15 (5) 2-(1,2-dimethyl-3-indolyl)-3-(2,4,5-trimethyl-3-thienyl) maleic anhydride
(6) 2-(methoxybenzo[b]thiophene-3-yl)-3-(1,2-dimethyl-3-indolyl) maleic anhydride

Spiroaromatics

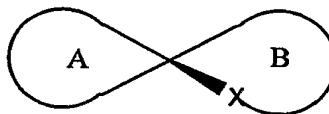
20 Spiroaromatics consist structurally of two carbocycles connected through a single carbon atom from which four extending bonds are bonding other carbon or heteroatoms. Of the four bonds, extending from the spirocarbon center, at least one is to a heteroatom allowing bond cleavage and ring opening under controllable conditions.

25 Spiropyrans are one class of spiroaromatics. Spiropyrans consist of a pyran ring linked via a common spirocarbon center to another heterocyclic ring. Irradiation of the colorless spiropyran with UV light causes heterolytic cleavage of the C-O bond forming the ring-opened colored species, often called the "merocyanine" form which can take on a cis-(1,2) or trans-(1,3) or the ortho-quinoidal form.

30 The pyran ring is usually a substituted benzo or naphthopyran but the heterocyclic component situated across the spirocarbon center can be chosen from

a long list of ring systems such as, and not limited to, indole, benzthiazole, benzoxazole, benzselenazole, quinoline, acridine, phenanthridine, benzopyran, naphthopyran, xanthane, pyrrolidine and thiazolidine.

Similarly to the arylethenes, the active material used in the present
5 invention may be any one of spiroaromatic materials of the general Formula II:



Formula II

wherein

- ring A represents a C5-C8 carbocycle, C4-C7 heterocycle containing at
10 least one heteroatom selected from N, O, or S; said N heteroatom may be further substituted by one or two groups selected from C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, hydroxyl, or -CH=CH-CN; when said
15 N heteroatom is tetrasubstituted it is positively charged and is associated with an anion selected from the group consisting of organic or inorganic anions;
said C5-C8 carbocycle or C4-C7 heterocycle may be substituted by one or more of the groups selected from halogen, C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-
20 C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, cyano, nitro, sulfo, hydroxyl, thiol, -CH=CH-CN, azido, amido or amino;
- ring B represents a substituted or unsubstituted heterocycle containing at least one heteroatom X, said X being selected from N, O, and S; wherein said N
25 atom may be further substituted by one or two groups selected from C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, hydroxyl, or -CH=CH-CN; when said N heteroatom is tetrasubstituted it is positively charged

and is associated with an anion selected from the group consisting of organic or inorganic anions;

and wherein said ring B may contain one or more endocyclic double bonds;

5 said rings A and B may be fused to one or more substituted or unsubstituted carbocycle, C4-C14 heterocycle, C6-C14 aryl or C4-C14 heteroaryl ring system;

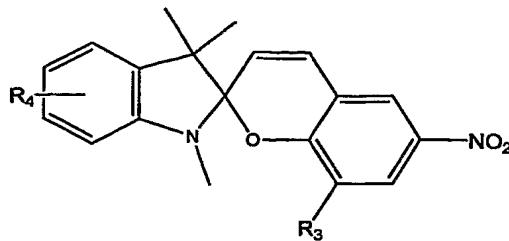
and wherein the compounds of Formula II may be neutral, charged, multiply charged, positively charged having an external anion, negatively 10 charged having an external cation or zwitterionic.

Preferably, the spiroaromatic compounds of Formula II are those in which rings A and B each represents a C4-C7 heterocycle containing at least one heteroatom selected from N, O, or S, and wherein said N heteroatom may be further substituted by C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 15 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic or -CH=CH-CN;

said C4-C7 heterocycle is substituted by one or more group selected from halogen, C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1- 20 C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, cyano, nitro, sulfo, hydroxyl, -CH=CH-CN, azido, amido or amino;

said rings A and B may contain one or more endocyclic double bond and may also be fused to one or more substituted or unsubstituted carbocycle, C4- 25 C14 heterocycle, C6-C14 aryl or C4-C14 heteroaryl ring system.

In a most preferred embodiment the spiroaromatic compounds of Formula II are spiropyran derivatives, preferably derivatives of 1',3',3'-trimethyl-6-nitro-spiro(2H-1-benzopyran-2,2'-2H-indole) as in formula III:



Formula III

wherein

- R3 is selected from the group consisting of H, halogen, C1-C12 alkyl, C2-5 C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, or azido; wherein said alkyl, alkenyl, alkynyl, aryl, heteroaryl, and non-aromatic carbocycle may be substituted by one or more group selected from halogen, hydroxyl, thiol, amino, 10 alkoxy, nitro, azido, or sulfo;

R4 is selected from C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, hydroxyl or -CH=CH-CN.

- 15 Specific, non limiting, Examples of the preferred compounds are the following:

- (7) 1',3',3'-trimethyl-6-nitro-spiro(2H-1-benzopyran-2,2'-2H-indole)
(8) 1',3',3'-trimethyl-6,8-dinitro-spiro(2H-1-benzopyran-2,2'-2H-indole)
(9) 6-(4-nitrophenylazo)-1',3',3'-trimethyl-spiro(2H-1-benzopyran-2,2'-2H-indole)
(10) 6-(4-chlorophenylazo)-1',3',3'-trimethyl-spiro(2H-1-benzopyran-2,2'-2H-indole)
(11) 1'-propyl-3',3'-dimethyl-6-nitro-spiro(2H-1-benzopyran-2,2'-2H-indole)
(12) 1',3',3',8-tetramethyl-5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridine-2,2'-2H-indole)

(13) 1',3',3',8-tetramethyl-spiro(2H-pyrano[2,3-c]pyridine-2,2'-2H-indole)

- In another specific embodiment, the spiroaromatic compounds used in the TTIs of the present invention are charged spiropyrans. Preferably, these 5 compounds are positively charged and are associated with a negatively charged counterion being an organic or inorganic counterion such as, but not limiting to, iodide, chloride, fluoride, bromide, carbonate, PF_6^- , BF_4^- , $(\text{phenyl})_4\text{B}^-$, benzoate hydroxide and the like. Non-limiting examples of the positively charged systems are the following:
- 10 **(14) 1',3',3', 7,8-pentamethyl -5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) iodide**
- (14a) 1',3',3', 7,8-pentamethyl -5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) chloride**
- (14b) 1',3',3', 7,8-pentamethyl -5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) hydroxide**
- (14c) 1',3',3', 7,8-pentamethyl -5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) benzoate**
- (14d) 1',3',3',7,8-pentamethyl-5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) hexafluorophosphate**
- 20 **(15) 1',3',3',7,8-pentamethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) iodide**
- (15a) 1',3',3',7,8-pentamethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) chloride**
- (15b) 1',3',3',7,8-pentamethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) benzoate**
- 25 **(15c) 1',3',3',7,8-pentamethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) hexafluorophosphate**
- (15d) 1',3',3',7,8-pentamethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) hydroxide**

In another specific embodiment, the spiroaromatic compounds are spirooxazine (16) or its derivatives, spironaphthoxazine (17) or its derivatives, and spiroindolinopyridobenzoxazine (18) or its derivatives, as shown in Appendix A.

- 5 As used therein, the term "*substituted*" refers to a radical in which any one or more of the existing C-H bonds is replaced by a C-W bond wherein the W atom may be any one or more of the indicated substituent groups, or a combination thereof. For example, the expression "*said...aryl...may be substituted by one or more group selected from halogen, hydroxyl, thiol, amino, alkoxy, nitro, azido, or sulfo*" refers to an aryl group possibly being substituted by the indicated groups, resulting in substituted aryl radicals such as, and not limited to, 4-chlorophenyl, 3-biphenyl, 1-aminopropane-2-ol-phenyl, 2-methylsulfonyl-3-nitromethoxyphenyl and the like.
- 10

The term "*derivative*" as used herein, refers to a compound similar in structure to the another compound, and which may be produced from said another compound in one or more steps as in replacement of H by an alkyl, acyl, amino or any other group. Also contemplated as derivatives are charged systems of their corresponding neutral compounds. For example, within the scope of the present invention, compound 14 is considered as a derivative of compound 12.

- 15
- 20 The term "*endocyclic double bond*" refers to cyclic radicals which contain one or more C=C, C=Y and/or Y=Y inner-cycle double bonds wherein C is a carbon atom and Y is a heteroatom such as, but not limiting to, N, O, or S. When Y is a divalent heteroatom such as O or S, the system may be charged. Examples for C=C and C=Y endocyclic double bonds are, without being limited to, cyclopentenyl, cyclohexenyl, benzopyrenyl, indolyl, 2H-benzo[e][1,3] oxazinyl, indazolyl and the like. The term "*exocyclic double bond*" refers to a cyclic radical which contains one or more C=C, C=Y and/or Y=Y out-of-ring double bond wherein Y is as defined above. Examples for cyclic radicals containing exocyclic double bond are, without limiting thereto, dihydrofuryldione, furyl-2,5-
- 25

dione, cyclopent-1-yl-3-one, 3,3,4,4-tetrafluoro-5-methylenecyclopenten-1-yl and the like.

- The term "*alkyl*" typically refers to a straight or branched alkyl radical and includes for example methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, *tert*-5 butyl, n-pentyl, 2,2-dimethylpropyl, n-hexyl and the like. Preferred alkyl groups are methyl, ethyl and propyl. The term "*alkenyl*" refers to a straight or branched hydrocarbon radicals typically having between 2 and 6 carbon atoms and one preferably a terminal double bond and includes for example vinyl, prop-2-en-1-yl, but-3-en-1-yl, pent-4-en-1-yl and the like. The terms "*alkoxy*", "*alkylthio*" 10 and "*alkanoyl*" refer to the groups alkyl-O-, alkyl-S-, and alkyl-CO- respectively, wherein "*alkyl*" is as defined above. Examples of alkoxy are methoxy, ethoxy, hexoxy and the like. Examples of alkylthio are methylthio, propylthio, pentylthio and the like, and examples of alkanoyl are acetyl, propanoyl, butanoyl and the like.
- 15 The term "*aryl*" as used herein refers to aromatic carbocyclic group having 6 to 14 carbon atoms consisting of a single ring or multiple rings such as phenyl, naphthyl, phenanthryl and the like. The term "*heteroaryl*" refers to monocyclic, bicyclic or tricyclic heteroaromatic group containing one to three heteroatoms selected from N, S and/or O such as, but not limited to, pyridyl, 20 pyrrolyl, furyl, thienyl, imidazolyl, oxazolyl, quinolinyl, thiazolyl, pyrazolyl, quinazolinyl, 1,3,4-triazinyl, 1,2,3-triazinyl, benzofuryl, isobenzofuryl, indolyl, imidazo[1,2-a]pyridyl, benzimidazolyl, benzthiazolyl and benzoxazolyl.
- The term "*halogen*" refers to fluoro, chloro, bromo or iodo. The term "perfluoro" or "perfluorated" refers to a radical in which all hydrogen atoms 25 were replaced by F atoms. For Example, a perfluorated methyl group refers to —CF₃.
- Also contemplated by the present invention are TTIs which use charged compounds of Formulas I, II or III. The negatively charged systems may be formed with metals or amines such as alkali and alkaline earth metals or organic 30 amines. Examples of metals used as cations are sodium, potassium, magnesium,

calcium and the like. The cations may also be quaternary salts such as a quaternary salt of the formula $-NRR'R'' + Z$ wherein R, R' and R'' each is independently hydrogen, alkyl or benzyl and Z is a counterion, including chloride, bromide, iodide, O-alkyl, toluenesulfonate, methylsulfonate, sulfonate, 5 phosphate, benzoate, borate or carboxylate.

Acid addition salts of the compounds include salts derived from inorganic acids such as hydrochloric, nitric, phosphoric, sulfuric, hydrobromic, hydroiodic, phosphorous and the like, as well as salts derived from organic acids such as aliphatic mono- and dicarboxylic acids, phenyl-substituted alkanoic acids, 10 hydroxyl alkanoic acid, aromatic acids, sulfonic acids and the like. Such salts thus include cations such as sulfate bisulfate, bisulfite, nitrate, phosphate, monohydrogenphosphate, metaphosphate, chloride, bromide, iodide, acetate, propionate, isobutyrate, oxalate, malonate and the like.

The acid addition salts forming positively charged compounds, to be used 15 with the TTIs of the present invention, may be prepared by contacting the free base derivatives of the compounds of general Formulas I, II or III with a sufficient amount of the desired acid to produce the salt in the conventional manner. The free base may be regenerated by contacting the salt form with a base and isolating the free base.

20 The positively charged systems may also be prepared by contacting the free base compounds with sufficient amounts of an alkylating agent such as alkylhalides, e.g., methyliodide, methylbromide and the like to affect substitution at the heteroatom. The negatively charged counterion, being an atom or a group, such as bromide, hydroxide, carbonate and the like may be replaced by a 25 different negatively charged counterion utilizing any method known in the art.

Within the scope of the present invention, the term "***charged heteroatom***" or "***charged heteroaryl***" refers to heteroaryl systems, as defined hereinbefore, being singly charged or multiply charged, having a localized charge or a delocalized charge.

Localized charge may reside on one or more atom. In case of a fully substituted heteroatom, such as tetrasubstituted N atom, the charge would be positive, as described hereinbefore. The heteroaryl may also be negatively charged, as described hereinbefore, wherein the heteroatom is partially substituted having an unbonding pair of electrons. In positively and negatively charged systems, carbon atoms may also take on the charge, not necessarily via delocalization of distant charge.

The term "*charged group*" refers to any one or more groups capable of taking on negative or positive charge or charges. Examples of such groups are ammonium, phosphonium, phenolate, carboxylate, sulphonate, thiolate, selenate and those mentioned herein before. The charge may be localized or delocalized and may be positive or negative. The term "**group substituted by another group having a charge**" refers to neutral radicals being substituted by charged groups as defined hereinbefore. The terms charged heteroatoms, charged heteroaryl, or charged group encompass zwitterionic systems as well.

The synthesis of the compounds used with the indicators of the present invention, may be prepared according to any synthetic route known in the literature. **Figs. 2, 6 and 7** show examples of such syntheses.

Depending on the specific application, a diarylethene or a spiroaromatic compound having the required behavior may be chosen. Most of the above systems and all of the examples are characterized by one uncolored thermodynamically stable state and one colored metastable state. Yet, these molecules are characterized by a relatively high optical quantum yield for the forward ring closure process (turning the molecules colored) and a substantially low optical quantum yield for the forward ring opening process (discoloration colored). In the colored state, only negligible effect is found to any stimulus other than temperature.

The metastable state of the compounds used with the TTIs of the present invention may be achieved by one of the various stimuli mentioned hereinabove. In one embodiment, the metastable state is generated by photonic induction,

wherein a matrix embedded with the substance is positioned or passed under a light source, emitting light of a wavelength and intensity suitable for photoexcitation, such as UV. The exposure to the light is terminated when the embedded substance changes its color to a color indicative of the formation of
5 the metastable state at a pre-fixed quantity.

In another embodiment, the metastable state is achieved by pressure induction. In this procedure, the matrix embedded with and/or atop the substance is passed between two bodies, such as metal rolls, which apply pressure onto the surface of the matrix thereby inducing the formation of the metastable state. By
10 adjusting the time and pressure imparted by the bodies to the active material, it is possible to control the degree of conversion from a stable state to a metastable state in the TTI active matrix.

In yet another embodiment, the metastable state is achieved by thermal induction. In this particular induction process, the matrix embedded with the
15 substance to be induced is heated to temperatures normally below the melting point of said substance. The heat may be applied by any method known. In one specific case, the heat is applied to the matrix while being passed through two heated metal rolls. In this case, the pressure applied to the surface is not capable itself of inducing the formation of the metastable state, but serves merely to
20 ensure controlled thermal contact between the heaters and the sample. The metastable state is achieved as a result of the heat transfer from the heaters, i.e., the metal rolls, which are in contact with the matrix and the matrix itself.

However, there may be instances where the use of any combination of pressure, light and thermal inductions may be desired or necessary. It is
25 therefore, a further embodiment of the present invention, to achieve the metastable state of the substances to be used with the TTIs of the present invention, by a combination of stimuli.

The support matrix used in the present invention may be a polymer such as PVC, PMMA, PEO polypropylene, polyethylene, all kinds of paper, all kinds
30 of printing media or the like or any glass-like film. The active indicator may be

introduced into and/or atop a matrix substrate such as polymers, glass, metals, paper, and the like, and may take on in the matrix any form that may permit reversibility of the induced chromic process. Such forms may be or result from indicator-doping of the matrix, sol-gel embedment of the indicator in the matrix,

5 embedment of the indicator as small crystallites, solid solution and the like.

In one case, the depositing of the active material in the process of producing the TTI of the present invention is by transforming it into a printable ink that is suitable for printing using any of the printing methods known in the art, e.g., ink jet printing, flexo printing, laser printing and the like.

10 In another specific embodiment, the active indicator is embedded in the matrix in the form of small crystallites. In another specific embodiment, the active indicator is embedded in the packaging material of the goods.

The substrates are suitable for use as packaging materials for the goods and or for attachment thereto by any method known. It should be understood, that
15 the indicators of the present invention may also be applicable to and used in the food industry, and essentially be similarly effective to other goods that may be used in the pharmaceutical or medical fields.

The invention will now be exemplified by the following non-limiting
20 examples.

Example 1: A time temperature indicator having a crystalline active matrix made of the diarylethene 3.

25 Crystals of 3 are photochromic in the crystal, forming a deep color upon illumination. In the dark, the cyclic photoproduct reverts to the stable colorless form ($\tau_{1/2}=37s$ at room temperature).

**Example 2: A time temperature indicator having a crystalline active matrix
30 made of N-propyl nitrospiropyrane (11).**

Synthesis- N-propyl nitrospiropyrane (**11**) was prepared as shown in **Fig. 2** by refluxing a mixture of 3,3-dimethyl-2-methylene-1-propyl-2,3-dihydro-1H-indole and 2-hydroxy-5-nitrobenzaldehyde in ethanol. The product was purified by 5 column chromatography and recrystallized from ethanol.

Properties- Compound **11** is photochromic in the crystal, forming a deep blue purple color upon illumination, as shown in **Fig. 3**. In the dark, the acyclic photoproduct reverts to the stable colorless form following a biexponential decay 10 curve, the fading rate being proportional to the aggregated heat adsorbed by the system and thus serving as an indicator to the time – temperature history it experienced during its colored period (**Fig. 4**).

Preparation of the TTI- Finely ground powder of colorless **11** was suspended in 15 an inert solvent and adsorbed onto a paper support. Alternatively, a solution of the compound in ethanol or an ether:hexane mixture was sprayed onto the appropriate surface, such as paper, and the solvent evaporated, resulting in crystallization of **11** in the support matrix. The active spot was surrounded by a reference color and encapsulated in between two plastic foils.

20 In another case, the substrate on which the active matrix is deposited is a transparent polypropylene which is covered and sealed after deposition of **11** with a polypropylene color filter designed to avoid photo re-charging as well as photo bleaching.

25 **Results-** Illumination of the TTI loaded with fine crystalline powder of **11** turned it deep blue. The illumination activates the system as a TTI and in the absence of any additional light illumination the system is sensitive only to the temperature and time. In the dark, the acyclic photoproduct form of the active matrix reverts to the stable colorless form, as shown in **Fig. 4**. The time-temperature profiles 30 that were recorded on the TTI of the present example are:

- At 31°C: having a $\tau_{1/2}=54$ min and 5 hrs
25°C: having a $\tau_{1/2}=2.5$ hrs and 16.6 hrs
7°C: having a $\tau_{1/2}=27.8$ hrs and 242.6 hrs
4°C: having a $\tau_{1/2}=44$ hrs and 397 hrs
5 2°C: having a $\tau_{1/2}=60$ hrs and 544 hrs

These results represent activation energies and pre-exponential factors of:

$Ea=21.9\pm0.9$ Kcal mol⁻¹, $A=11.3\pm0.8$ and

$Ea=23.4\pm0.8$ Kcal mol⁻¹, $A=13.2\pm0.6$, as shown in Fig. 5.

- 10 The fading rate is proportional to the aggregated heat adsorbed by the system and thus is serving as an indicator to the time – temperature history it experienced during its colored period.

Example 3: Time temperature indicators having a crystalline active matrix made of ionic spirobopyranes.

- Synthesis-** Ionic spirobopyranes **14** and **15** were prepared by refluxing 3,3-dimethyl-2-methylene-1-methyl-2,3-dihydro-1H-indole and the respective salicaldehyde derivative in ethanol, yielding the spiro compounds **12** and **13**, 20 shown in Figs. 6 and 7, respectively. The neutral spiro compounds **12** and **13** were then quaternized, as shown, in the presence of methyl iodide, producing the ionic spirobopyranes **14** and **15**. The products were easily purified by recrystallization from methanol.

- Properties-** Compounds **14** and **15** were found to be photochromic in the crystalline state forming a deep red to purple color upon illumination. In the dark, the acyclic photoproducts revert to their stable colorless forms. The fading rate which is proportional to the aggregated heat adsorbed by the systems and makes these compounds suitable as indicators to the time – temperature history they 30 experienced during their colored period.

In the crystalline state, the photoactivity of **14** and **15**, as well as its thermal reversion vary as a function of the specific material but also a function of the specific crystal packing, the later being defined both by the cation but also by the nature and properties of the anion. By changing the anion, either by ion exchange chromatography or by co-precipitation from anti solvent or by any other means known in the art, one can obtain crystalline materials of the same organic substance having different time temperature profiles, thus producing different TTIs having different time-temperature profiles of the same organic substance.

10

Example 4: A piezochromic time temperature indicator that is charged by pressure.

Ionic spiropyranes **14** and **15** are piezochromic, turning colored upon applied pressure. Passing a crystalline sample in between two metal drums induces the 15 coloration of the crystals, the spectrum being similar to the photoactivated one. The time-temperature characteristics of the systems were found to be similar to identical systems that were activated by light (results not shown).

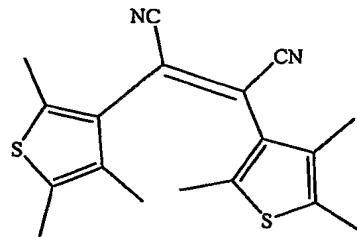
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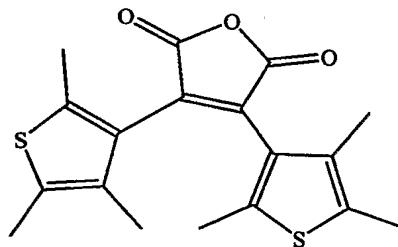
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Appendix A:

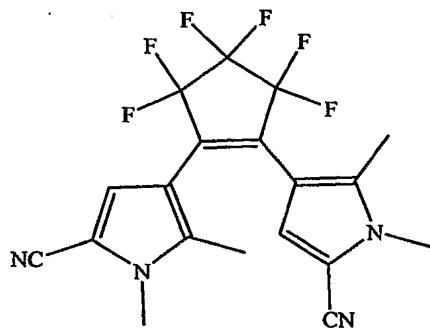
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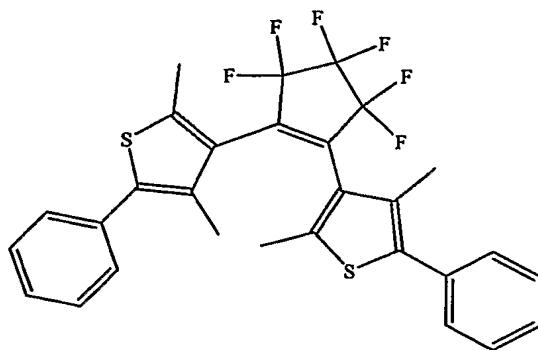


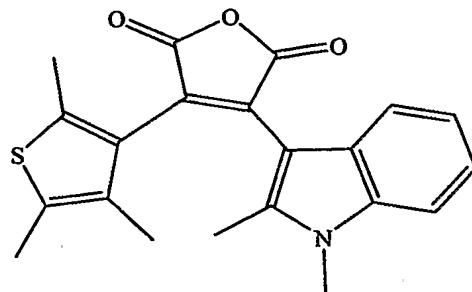
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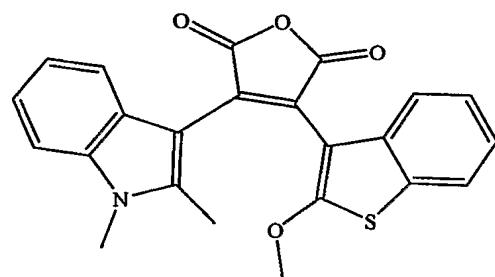
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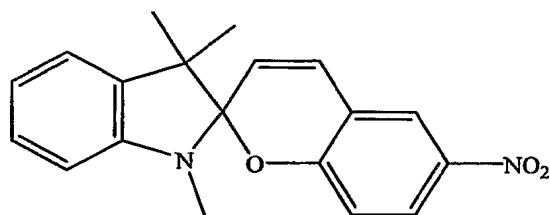


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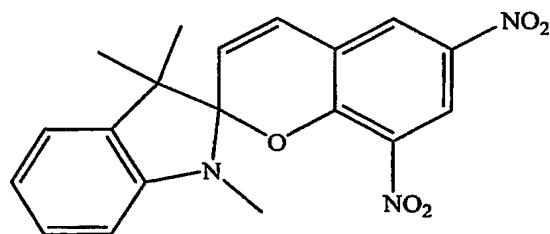


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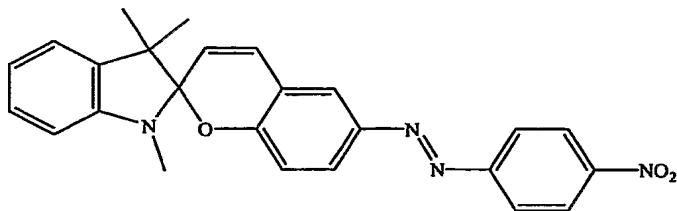


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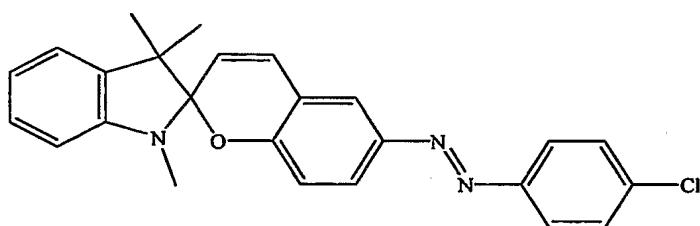


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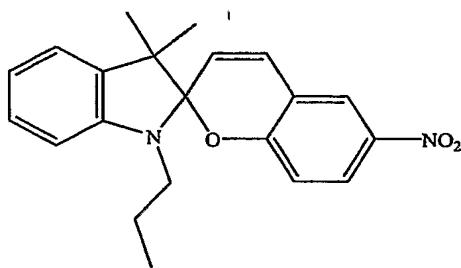
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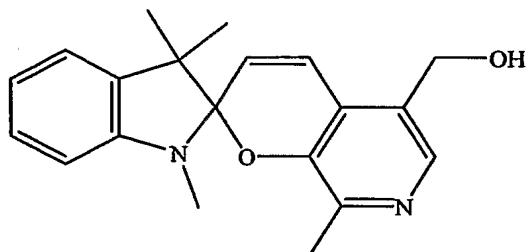
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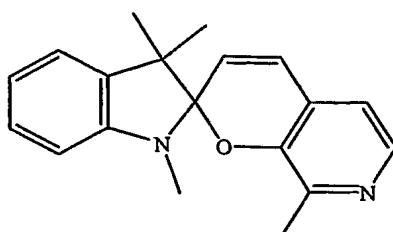
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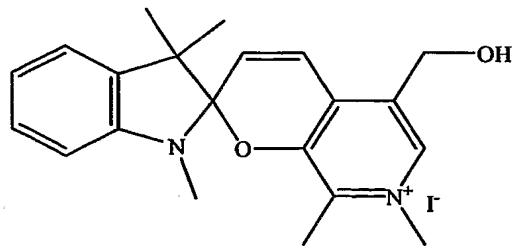


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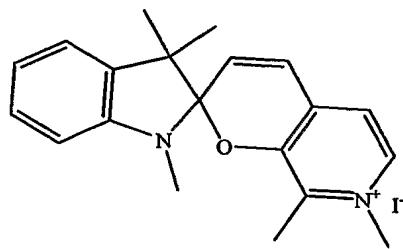


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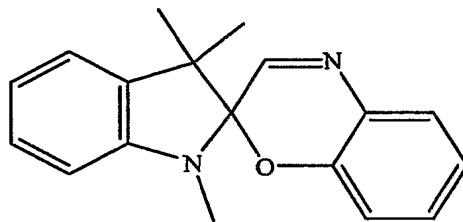
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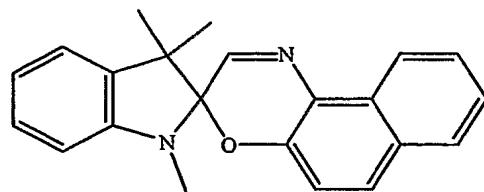
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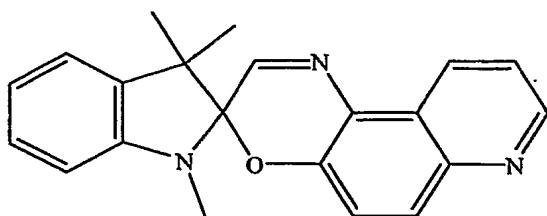
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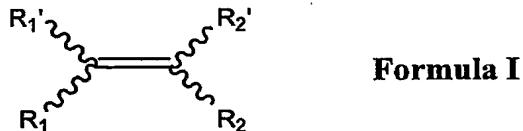


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CLAIMS:

1. A time-temperature indicator (TTI) comprising an active material including at least one compound selected from diarylethenes and spiroaromatics.
2. A time-temperature indicator (TTI) comprising an active material including at least one compound selected from diarylethenes and spiroaromatics, wherein at least one compound is in a crystallite form.
- 5 3. The TTI of Claim 1 or 2, wherein the diarylethene is of Formula I



10

wherein

R1 and R2 each independently represents C6-C14 aryl, C4-C12 heteroaryl, conjugated heterocyclic; wherein said heteroaryl and conjugated heterocyclic may contain one to three heteroatoms selected from N, O, or S; and

15 wherein said aryl, heteroaryl, or conjugated heterocyclic may be substituted by one or more halogen, hydroxyl, thiol, amino, C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, cyano, nitro, sulfo, -CH=CH-CN, azido, or

20 amido;

R1' and R2' each independently represents H, cyano, nitro, sulfo, hydroxyl, thiol, -CH=CH-CN, or amido; or substituted or unsubstituted C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic; or R1' and R2' together with the carbon atoms to which they are attached form a C5-C8 carbocyclic ring or a C4-C7 heterocyclic ring containing one to three endocyclic or exocyclic heteroatoms selected from N, O, or S; said N heteroatom may be

further substituted by H, or by one or two substituted or unsubstituted groups selected from C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic
5 heterocyclic, hydroxyl, or -CH=CH-CN; when said N heteroatom is tetrasubstituted it is positively charged and is associated with an anion selected from the group consisting of organic or inorganic anions;

R1, R1', R2 and R2' may each independently represent a charged group or a group substituted by another group having a charge; said charge may be
10 localized or delocalized and may be positive or negative;

and wherein said R1 and R2 may be in a *cis* or *trans* conformation.

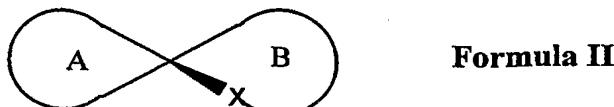
4. The TTI of Claim 3, wherein R1 and R2 are each independently a substituted heteroaryl containing one to three heteroatoms selected from N, O, or S; wherein said heteroaryl is substituted by one or more halogen, C1-C12 alkyl,
15 C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, cyano, nitro, sulfo, -CH=CH-CN, azido, amido or amino; R1' and R2' each independently represents H, C1-C12 alkyl, C2-C12 alkenyl, cyano, nitro, or -CH=CH-CN, or R1' and R2' together with the carbon atoms to which they are attached form a C5-C8 carbocyclic ring
20 or a C4-C7 heterocyclic ring containing one to three endocyclic or exocyclic heteroatoms selected from N, or O; said N heteroatom is further substituted by H, or by a substituted or unsubstituted C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, or -CH=CH-CN; and wherein said C5-C8 carbocycle is substituted by
25 one or more halogen, preferably by one or more fluoro atoms.

5. The TTI of Claim 4, wherein said C5-C8 carbocycle is substituted by one or more fluoro atoms.

6. The TTI of Claim 3, wherein R1 and R2 are identical and are selected from substituted or unsubstituted indoles, pyrroles, thiophenes, benzthiophenes

or furans. In this embodiment R1' and R2' are also identical and are selected from cyano, C1-C6 alkyl, or C6-C14 aryl.

7. The TTI of Claim 3, wherein R1 and R2 are selected from substituted or unsubstituted thiophenes, benzthiophenes, indoles or pyrroles; and R1' and R2'
5 together with the carbon atoms to which they are attached form a cyclopentyl, cyclohexyl, or an anhydride ring; said cyclopentyl or cyclohexyl being further substituted by one or more halogen, C1-C6 alkyl, C6-C14 aryl, hydroxyl, amino, nitro, or cyano groups.
8. The TTI of Claim 7, wherein the cyclopentyl or cyclohexyl are
10 substituted by halogens.
9. The TTI of Claim 8, wherein the cyclopentyl or cyclohexyl are perfluorinated.
10. The TTI of Claim 3, wherein the diarylethene of Formula I is symmetric.
11. The TTI of Claim 10, wherein the diarylethenes of Formula I includes at
15 least one of the following: 1,2-dicyano-1,2-bis(2,4,5-trimethylthiophene-3-yl)ethane; 2,3-bis(2,4,5-trimethylthiophene-3-yl)maleic anhydride; 1,2-bis(2-cyano-1,5-dimethyl-4-pyrrolyl)perfluorocyclopentene; and 1,2-bis(2,4-dimethyl-5-phenylthiophene-3-yl)perfluorocyclopentene.
12. The TTI of Claim 3, wherein the diarylethene of Formula I is
20 asymmetric.
13. The TTI of Claim 12, wherein the diarylethenes of Formula I includes at least one of the following: 2-(1,2-dimethyl-3-indolyl)-3-(2,4,5-trimethyl-3-thienyl) maleic anhydride; and 2-(methoxybenzo[b]thiophene-3-yl)-3-(1,2-dimethyl-3-indolyl) maleic anhydride.
- 25 14. The TTI of Claim 1 or 2, wherein the spiroaromatics are of Formula II:



wherein

- ring A represents a C5-C8 carbocycle, C4-C7 heterocycle containing at least one heteroatom selected from N, O, or S; said N heteroatom may be further substituted by one or two groups selected from C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, 5 C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, hydroxyl, or -CH=CH-CN; when said N heteroatom is tetrasubstituted it is positively charged and is associated with an anion selected from the group consisting of organic or inorganic anions;
- said C5-C8 carbocycle or C4-C7 heterocycle may be substituted by one or 10 more of the groups selected from halogen, C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, cyano, nitro, sulfo, hydroxyl, thiol, -CH=CH-CN, azido, amido or amino;
- 15 ring B represents a substituted or unsubstituted heterocycle containing at least one heteroatom X, said X being selected from N, O, and S; wherein said N atom may be further substituted by one or two groups selected from C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic 20 carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, hydroxyl, or -CH=CH-CN; when said N heteroatom is tetrasubstituted it is positively charged and is associated with an anion selected from the group consisting of organic or inorganic anions;
- and wherein said ring B may contain one or more endocyclic double 25 bonds;
- said rings A and B may be fused to one or more substituted or unsubstituted carbocycle, C4-C14 heterocycle, C6-C14 aryl or C4-C14 heteroaryl ring system;

and wherein the compounds of Formula II may be neutral, charged, multiply charged, positively charged having an external anion, negatively charged having an external cation or zwitterionic.

15. The TTI of Claim 14, wherein the spiroaromatic compounds of Formula II are those in which rings A and B each represents a C4-C7 heterocycle containing at least one heteroatom selected from N, O, or S, and wherein said N heteroatom may be further substituted by C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring 10 non-aromatic heterocyclic or -CH=CH-CN;

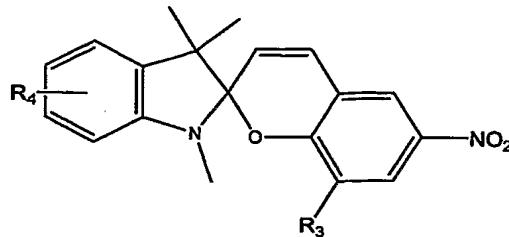
15. said C4-C7 heterocycle is substituted by one or more group selected from halogen, C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, cyano, nitro, sulfo, hydroxyl, -CH=CH-CN, azido, amido or amino;

15. said rings A and B may contain one or more endocyclic double bond and is fused to one or more substituted or unsubstituted carbocycle, C4-C14 heterocycle, C6-C14 aryl or C4-C14 heteroaryl ring system.

16. The TTI of Claim 14, wherein the spiroaromatic compounds of Formula II are spiropyran derivatives.

17. The TTI of claim 16, wherein the spiroaromatic compounds of Formula II are selected from: 1',3',3',8-tetramethyl-5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridine-2,2'-2H-indole) and 1',3',3',8-tetramethyl-spiro(2H-pyrano[2,3-c]pyridine-2,2'-2H-indole).

25 18. The TTI of Claim 16, wherein the spiropyran derivatives are derivatives of 1',3',3'-trimethyl-6-nitro-spiro(2H-1-benzopyran-2,2'-2H-indole) as in formula III:



Formula III

wherein

- R3 is selected from the group consisting of H, halogen, C1-C12 alkyl, C2-5 C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, or azido; wherein said alkyl, alkenyl, alkynyl, aryl, heteroaryl, and non-aromatic carbocycle may be substituted by one or more group selected from halogen, hydroxyl, thiol, amino, 10 alkoxy, nitro, azido, or sulfo;

R4 is selected from C1-C12 alkyl, C2-C12 alkenyl, C2-C12 alkynyl, C1-C6 alkanoyl, C1-C6 alkoxy, C1-C6 alkylthio, C6-C14 aryl, C4-C14 heteroaryl, C3-C8 membered non-aromatic carbocyclic, C3-C8 membered ring non-aromatic heterocyclic, hydroxyl or -CH=CH-CN.

- 15 19. The TTI of Claim 14, wherein the compounds of Formula II include at least one of the following: 1',3',3'-trimethyl-6-nitro-spiro(2H-1-benzopyran-2,2'-2H-indole); 1',3',3'-trimethyl-6,8-dinitro-spiro(2H-1-benzopyran-2,2'-2H-indole); 6-(4-nitrophenylazo)-1',3',3'-trimethyl-spiro(2H-1-benzopyran-2,2'-2H-indole); 1'-propyl-3',3'-trimethyl-6-nitro-spiro(2H-1-benzopyran-2,2'-2H-indole); and 6-(4-chlorophenylazo)-1',3',3'-trimethyl-spiro(2H-1-benzopyran-2,2'-2H-indole).

20. The TTI of claim 16, wherein the spiroaromatic compounds are charged.

21. The TTI of claim 20, wherein the charged compounds are positively charged.

25 22. The TTI of claim 20, wherein the charged compounds are negatively charged.

23. The TTI of claim 20, wherein the charged compounds are zwitterionic.

24. The TTI of claim 20, wherein the charged compounds are multiply charged.
25. The TTI of claim 21, wherein the positively charged compounds include one of the following: 1',3',3', 7,8-pentamethyl -5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) iodide; 1',3',3', 7,8-pentamethyl -5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) chloride; 1',3',3', 7,8-pentamethyl -5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) hydroxide; 1',3',3', 7,8-pentamethyl -5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) benzoate; 1',3',3',7,8-pentamethyl-5-hydroxymethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) hexfluorophosphate; 1',3',3',7,8-pentamethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) iodide; 1',3',3',7,8-pentamethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) chloride; 1',3',3',7,8-pentamethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) benzoate; 1',3',3',7,8-pentamethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) hexafluorophosphate; 1',3',3',7,8-pentamethyl-spiro(2H-pyrano[2,3-c]pyridinium-2,2'-2H-indole) hydroxide.
26. The TTI of Claim 16, wherein the spiroaromatic compounds include at least one of the following: spirooxazine or its derivatives, spironaphthoxazine or its derivatives, and spiroindolinopyridobenzoxazine or its derivatives.
27. The TTI of Claim 1, wherein said at least one compound is in a crystallite form.
28. The TTI of Claim 1, wherein said at least one compound is a solid solution.
29. The TTI of Claim 1, wherein said at least one compound being in a crystallite or solid solution form is embedded in a matrix.
30. The TTI of Claim 29, wherein said matrix is selected from the following: PVC, PMMA, glass, PEO, polypropylene, polyethylene, paper, printing media or glass-like film.

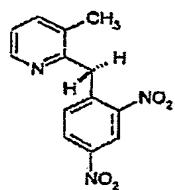
31. A method for manufacture of a TTI comprising an active material including at least one compound selected from diarylethenes and spiroaromatics, said method comprising:

- 5 1. embedding in or a top a suitable matrix said at least one compound;
2. inducing formation of a metastable state of the embedded said at least one compound of (1);

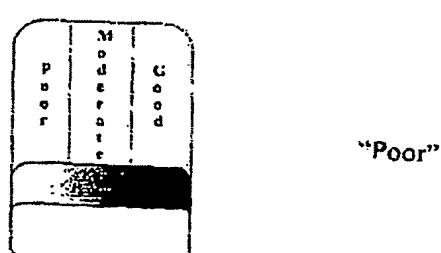
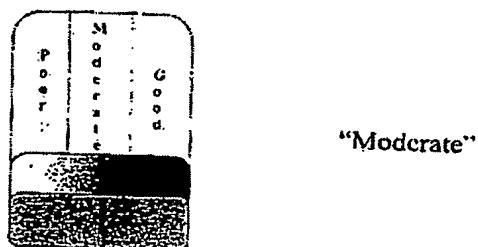
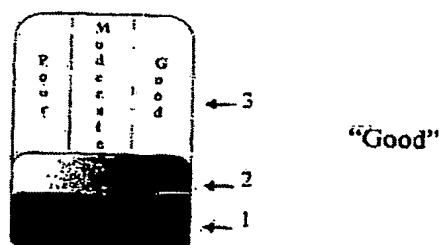
thereby providing a TTI comprising an active material.

32. The method of claim 31, further comprising the covering said TTI with a suitable cover support.

10 **33.** The method of claim 32, wherein said cover support is designed to avoid photo recharging or photo bleaching.



Prior Art
Fig. 1A



Prior Art
Fig. 1B

2/6

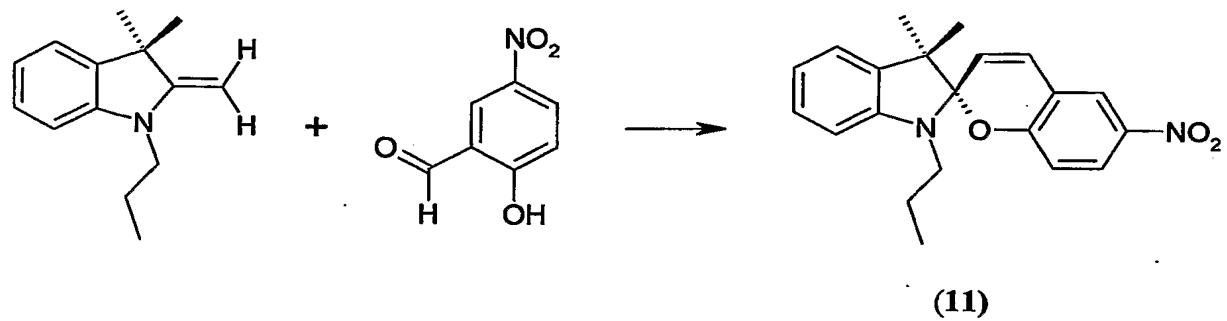


Fig. 2

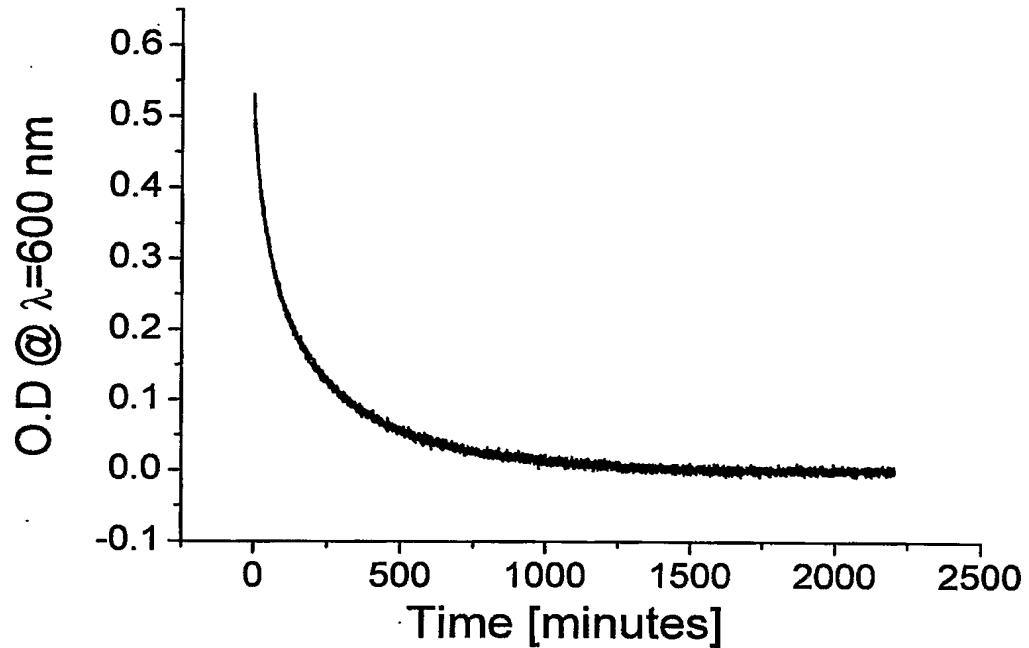


Fig. 3

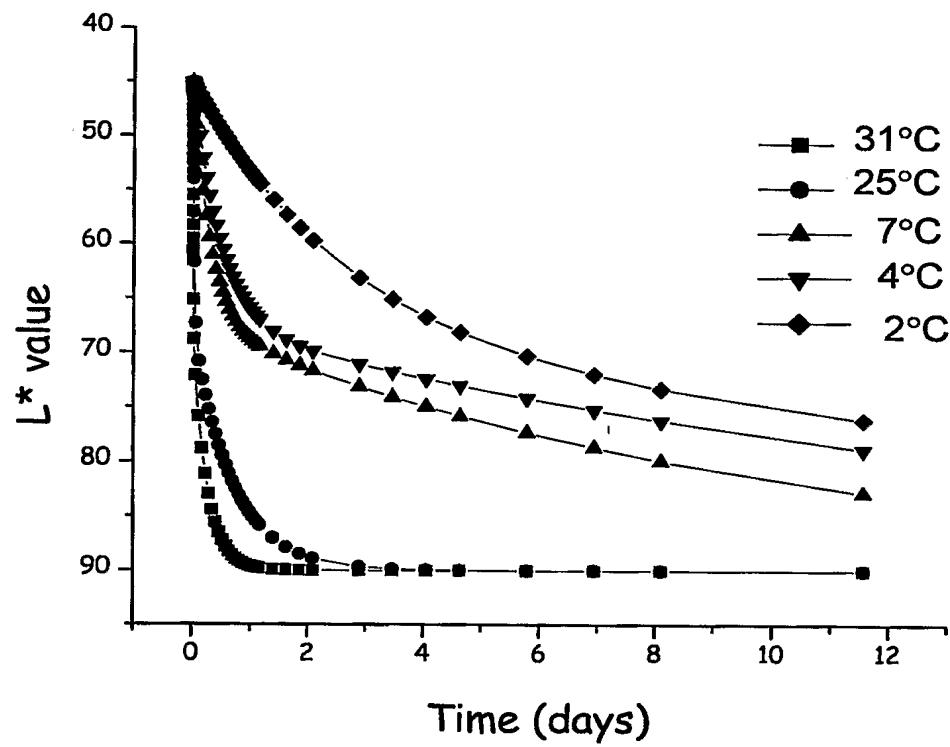


Fig. 4

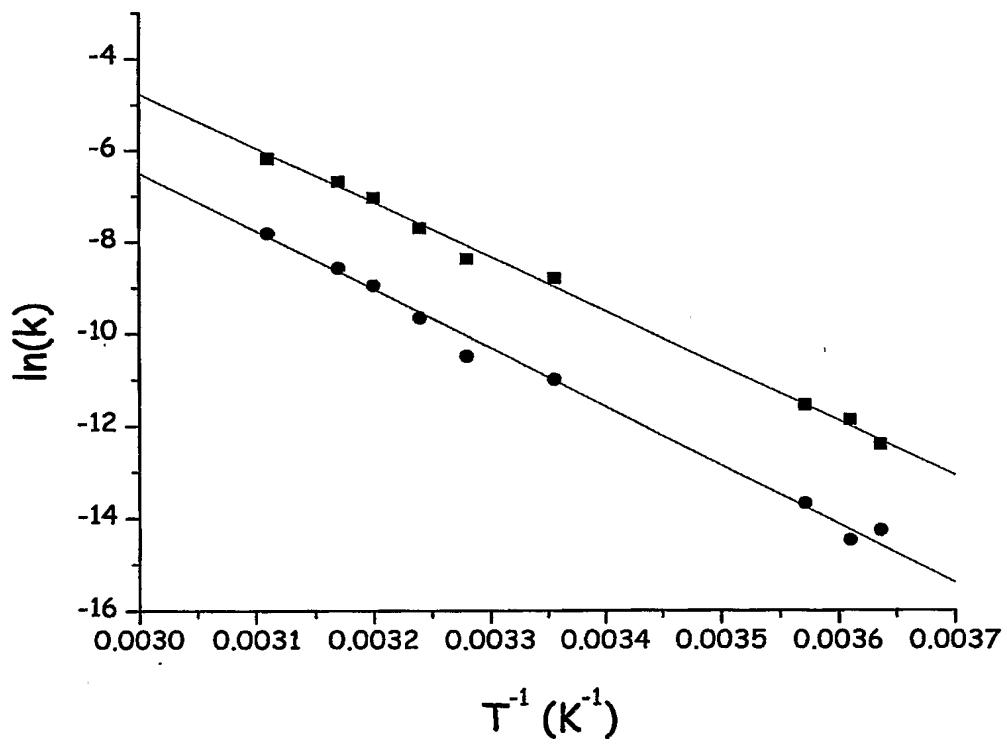


Fig. 5

5/6

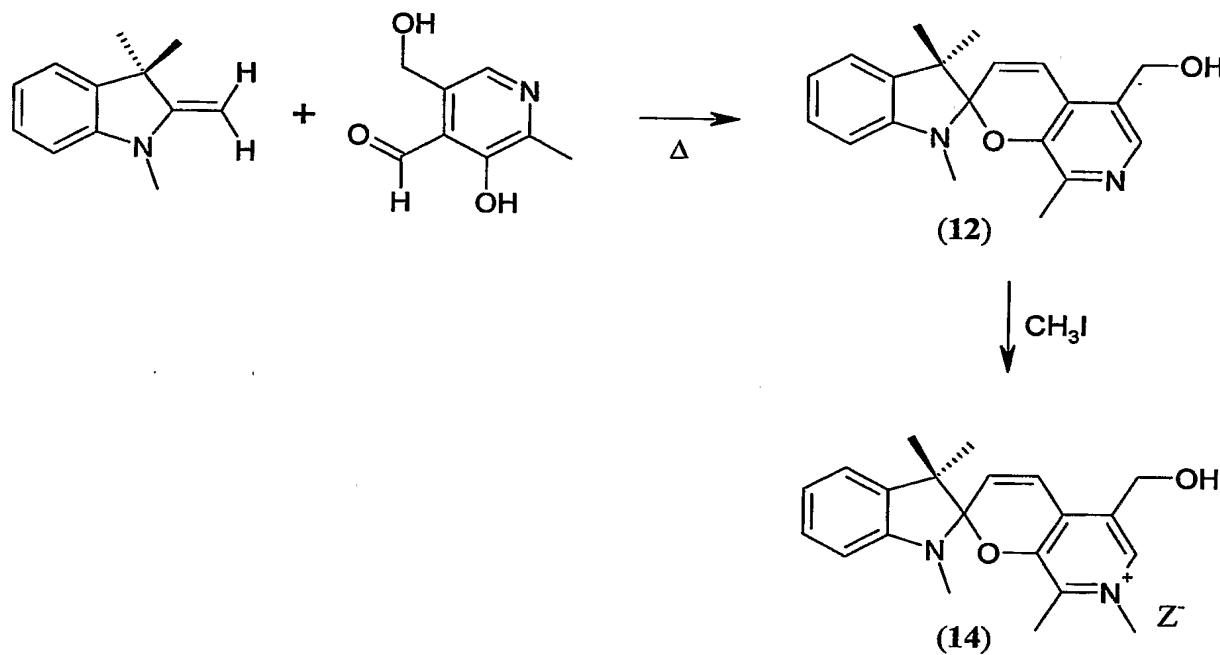


Fig. 6

6/6

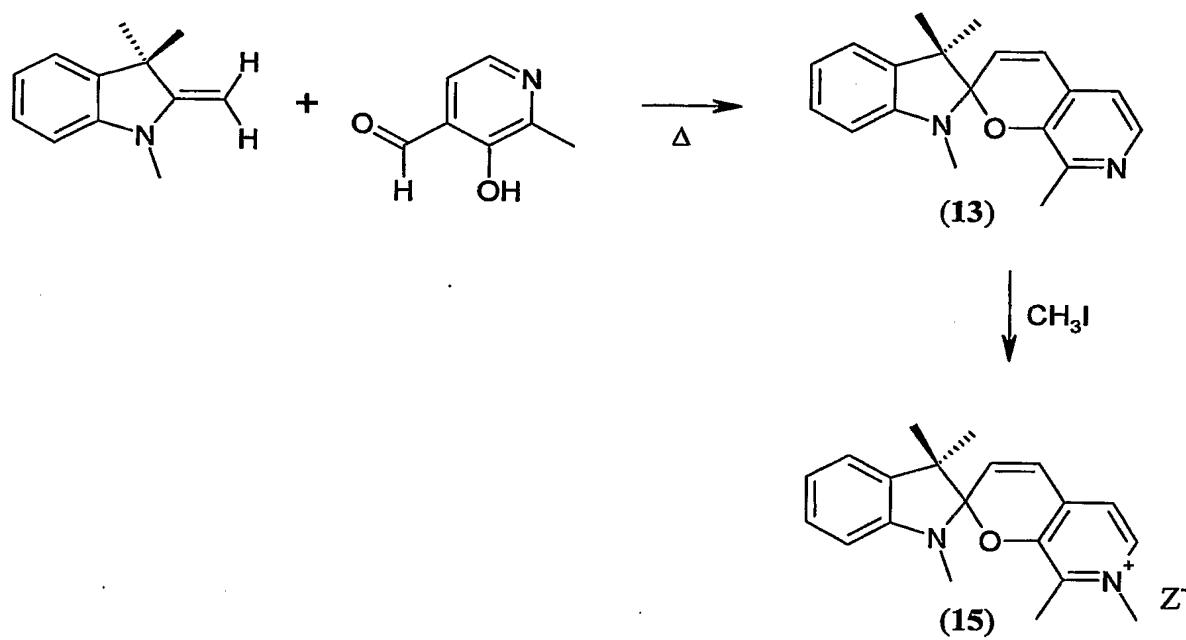


Fig. 7